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U. S. NAVAL TECHNICAL MISSION TO JAPAN
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15 December 1945

RESTRICTED

From: Chief, Naval Technical Mission to Japan.
To : Chief of Naval Operations.

Subject: Target Report - Japanese Magnetic Airborne Detector.

Reference: (a)"Intelligence Targets Japan" (DNI) of 4 Sept. 1945.

1. Subject report, covering Target E-14 of Fascicle E-1 of reference (a), is submitted herewith.

2. The investigation of the target and preparation of the report were accomplished by Lt.(jg) E. Snow, USNR.

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30612

JAPANESE MAGNETIC AIRBORNE DETECTOR

"INTELLIGENCE TARGETS JAPAN" (DNI) OF 4 SEPT. 1945

FASCICLE E-1, TARGET E-14

DECEMBER 1945

U.S. NAVAL TECHNICAL MISSION TO JAPAN

SUMMARY

ELECTRONICS TARGETS

JAPANESE MAGNETIC AIRBORNE DETECTOR

MAD research was started in June 1942 when adequate measures were needed to combat the U.S. submarine offensive. January 1943 saw the completion of the first airborne model, and tests were conducted at YOKOSUKA to determine the efficiency of MAD equipment. Detection range was 90 meters, but this was improved to 120 meters after six months work on the elimination of noise caused by eddy currents generated within the plane.

Production of the Type 3 Mark 1 MAD Equipment was started in October 1943, and the first models were delivered to the Navy six months later. In 1944, the peak production year, 465 complete installations were delivered to the Navy. Since the Army did no work in the MAD field, the Navy gave 137 sets to the Army for A/S patrols.

MAD was used in convoy escort with usually six planes flying across the bow of the group. In case of a slow convoy satisfactory coverage could be achieved with only three planes. Tactics generally were developed to conform with the supply of planes and fuel available in the theater.

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REFERENCES

Location of Targets:

Magnetic Section, Second Naval Technical Institute
Umehara Summer Resort, ZUSHI
Suzuki Summer Resort, HAYAMA

Japanese Personnel Who Assisted in Gathering Documents:

Lieut. I. MUKOYAMA, IJN, Aircraft Instrument Section, Naval Air Headquarters, TOKYO
Comdr. S. BABA, IJN, Chief, Aircraft Instrument Section, Naval Air Headquarters, TOKYO
Capt. J. OSHIMA, IJN, Chief, Magnetic Research Section, Second Naval Technical Institute, ZUSHI

Japanese Personnel Interviewed:

Lt. Comdr. T. OKAMOTO, IJN, Staff Officer of First Escort Fleet Air Squadron and General Headquarters, Grand Escort Fleet, Naval Aviator
Comdr. S. BABA, IJN, Technical Officer, Chief, Aircraft Instrument Section, Naval Air Headquarters, TOKYO
Capt. J. OSHIMA, IJN, Technical Officer, Chief, Magnetic Research Section, Second Naval Technical Institute, ZUSHI. (Twenty years in Navy, with last four years devoted to magnetic research in KURE and KANAZAWA.)
Lt. Comdr. KIOHARA, IJN, Chief, Research Section, Magnetic Research Section, Second Naval Technical Institute, ZUSHI. (Ten years in Navy as technical officer.)
Lieut. Y. YOSHITANE, IJN, Research Assistant, Magnetic Research Section, Second Naval Technical Institute, ZUSHI. (Graduate of Waseda College of Engineering; has been in Navy since 1943.)
K. SHIBATA, Naval Technician, Research Engineer, Magnetic Research Section, Second Naval Technical Institute, ZUSHI. (First man to conceive idea of MAD after seeing English magnetic loop in HONGKONG, December 1941. Has been engaged actively in all phases of MAD and magnetic research since that time. Has been in Navy for eight years.)
G. HAKATA, Development Engineer, Sumitomo Communications Co., Inc. (now Nippon Electric Co., Inc.) (Developed the Special Mark 1 MAD from his land mine detector research.)

INTRODUCTION

The possession of MAD equipment by the Japanese was discovered by JICPOA late in 1944, with TAIU picking up parts of this equipment throughout 1945. In February 1945, a TAIU field team in China was able to salvage an amplifier and dynamotor, while a search coil unit was found on Okinawa. All this equipment was sent to Anacostia for investigation, but little could be achieved since the equipment was not in operating order when recovered. Little documentary evidence of MAD equipment or its theory was found during the war. POWs were able to give a few details on tactics, but no information on theory or research. This left the field completely new and untouched when NavTechJap started its investigation of the problem in Japan.

The information on MAD was obtained with the assistance of the Naval Air Headquarters, TOKYO, which arranged interviews, gathered documents, and packed for shipment to the U.S. six of the latest MAD equipments. Complete cooperation was received from the MAD engineers and officers, who spent two weeks in their laboratory in ZUSHI adjusting this equipment for shipment.

The field was covered from the inception of MAD to the latest models developed by private concerns, which were not yet in production. The documents collected give the complete theory, operating characteristics, and installation data on the Type 3 Mark 1 MAD Equipment, which was the standard detector to the end of the war.

THE REPORT

PART I - DEVELOPMENT AND HISTORY

In December 1941, K. SHIBATA, a naval technician, was sent to HONGKONG to study a captured magnetic loop used by the British for harbor defense. He brought the loop to KURE for further investigation, where other aspects of magnetic detection were studied. It was first mounted on ships, but proved unsatisfactory, since the rolling and pitching of the ship made detection impossible. The airborne problem was given to the Meter Department of the First Naval Technical Institute, near YOKOSUKA, and research began in June 1942. The project received high priority because the U.S. submarine menace was growing from day to day. The Army conducted no research on MAD equipment.

The first model used two coils for differential action, but in October 1942 this system was discarded because mounting two coils presented many problems. The electrical interference induced by the pitching and rolling of the plane was solved to some degree by mounting the search coil in a gyro. To further eliminate the effect of the planes's vibration and shock, it was decided that a DC carrier type amplifier should be used. In January 1943 the first practical tests of the laboratory model were carried out on a Type 96 Land Attack Plane in YOKOSUKA. Various tests to determine the signal to noise ratio were attempted, and a maximum range of 90 meters above a small vessel (1000 tons) was obtained.

The following deductions were made:

1. As far as possible, metallic material of any kind should be removed from the immediate vicinity of the search coil.
2. Amplifier and search unit should be shock-mounted.
3. The pilot should keep the plane in level flight.
4. CRT should be used as an indicator unit.

It was assumed that if the above steps were taken, the range could be increased to 100 meters; however, a CRT never was used in actual practice.

From February to June 1943 the experimental model was adapted for practical use by appreciably decreasing the weight and size of the equipment. An electrically driven (Anschutz type) gyro was substituted for the large, heavy air-driven model. A low pass filter (see Figure 1), under one cycle per second, took care of the new noise caused by the electric drive. From June to November 1943, the production prototypes were installed on planes and tests were conducted on operation use. The YOKOSUKA Air Group was in charge of these tests and found that the main sources of trouble were the eddy current noises generated by the engine, control and guy wires. (See Part II) The ball bearings in the search coil rotating mechanism also were a source of noise and interference. Various substitutes were devised for the bearings, with bronze giving the best final results. Parts of the tail surfaces were made of wood and, whenever practicable, duraluminum was substituted for steel. The problem of noise was never completely solved and research still was in progress at the time the war ended.

When all the latest changes and innovations were made, the effective range was increased from 90 to 120 meters (390 feet). This was the Type 3 Mark 1 Magnetic Airborne Detection Equipment and was the standard equipment to the end of the war. When it was finally decided actually to put this model into production, it was realized that the range was not sufficient for satisfactory operational use. However, the committee in charge of the tests for the Navy Ministry came to the following conclusion:

Although we realize that the search range is limited, there is no other device at the present time that will detect submerged submarines. For this reason, we recommend that this apparatus be exploited and put to immediate use.

While the Type 3 Mark 1 was in production, the Navy ordered the various companies to develop improvements. Mr. HAKATA of the Sumitomo Communications Company (now the Nippon Electric Company) was engaged in research on a new land mine detector. He took this new principle and applied it to a new type of MAD equipment which in many theoretical aspects was far superior to the standard Type 3 Mark 1 (see Part II). This new model was in only the experimental stages when the war ended, but ranges up to 170 meters (550 feet) were obtained in June 1945.

It was decided not to put this new model into production since the change-over of assembly lines and tactical doctrine would be too difficult, and the slight increase in range was not deemed sufficient to warrant the work involved to make such changes.

PART II - THEORY OF OPERATION

A. General Description of Type 3 Mark 1 MAD Equipment

1. Fundamental Principle

This apparatus was designed to locate the position of a submarine by detecting the variation in the earth's magnetic field caused by the presence of a submarine. This variation in the earth's magnetic field causes a slight change of e.m.f. induced in the search coil, which is mounted in an aircraft. Since this detected variation is very small, a very sensitive amplifier is needed in order to build the signal up to usable level.

In order to prevent the spurious responses which would be caused by the pitch and roll of the aircraft, the search coil is gyro-stabilized.

Another source of trouble was the noise caused by the eddy current field produced in the metallic parts of the aircraft. When the aircraft deviated even slightly from a perfectly straight and level course, a change in the eddy current field was produced which was picked up by the search coil. In order to eliminate this source of noise, two coils were provided, one, the "compensating outer coil", was fixed to the fuselage: the other, the "compensating inner coil", was wound on the search coil.

These two coils and a variable resistor were connected in series. The outer coil produced an e.m.f. proportional to and in phase with the eddy current noise, because it cut the earth's field of flux in the same manner as the metallic parts of the aircraft which produced the noise. This e.m.f. generated a current in the inner coil, which, when properly adjusted by means of the variable resistor, could produce a field opposite in phase and equal in magnitude to the eddy current noise.

2. Component Parts

Parts	Function	Weight	
		kg	lbs
Search coil w/gyroscope	Picks up signal	10.0	22.0
Filter	Eliminates noise voltage of frequencies above 1.2 cps	5.3	11.7

Parts	Function	Weight	
		kg	lbs
Amplifier Indicator	Amplifies signal voltage. Signal discrimination, monitoring, indicating	23.0	50.6
Eddy current compensator	Compensates for eddy current noise	5.6	12.3
AC generator	Gyroscope power source	6.5	14.3
DC generator	Amplifier-Indicator power source	7.0	15.4
Position marker	Marks position of submarine	1.2	2.6

3. Construction and Function of Component Parts

a. Search Coil

The search coil consists of two coils, one above and one below the gyroscope case. Each coil is wound on a permalloy core and is covered with a metallic case. The compensating inner coil is wound on the outer layer of the search coil. One end of the permalloy core is set free to avoid mechanical stresses.

The search coil has the following characteristics:

Electrical resistance of coil ...... 15,000 ohms
Number of turns 16,000
Size of wire........................ 0.1mm E.C.W.
Permalloy core .... Ni 78% alloy
Bobbin Each coil consists of 3 bobbins of dulamince
Sensitivity of search coil... 1000 μV per degree per second (angular velocity) when axis of coil is perpendicular to the earth's field.

b. Gyroscope

The gyroscope is used to stabilize the search coil. It is of the Anshutz type (Induction motor driven) and has the following characteristics:

Diameter 130mm
Weight .... 2 kg (4.4 lbs)
Power requirements 3 phase,400cps,100 V, 0.8 A*
Time to reach peak speed ..... 10 to 15 minutes
Number of revolutions .... 19,500 ± 1500 RPM
Moment of inertia .... 50,000 gm/cm^2
*Made from phenol resin insulator to prevent eddy current noise.

A damping device is set on top of the coil cylinder to absorb the neutation.

c. Filter

A low filter is used in the input to the amplifier to discriminate

against high-frequency magnetic noise. The filter is of the π type with a cut-off frequency of 1.2 cycles per second and an attenuation of 40 decibels at 5 cycles per second.

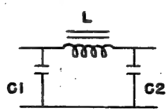

Figure 1
FILTER CIRCUIT

$L = 400_0 H$

$C_1 = 6\ \mu f$

$C_2 = 5\ \mu f$

d. <u>Amplifier</u>

The low-frequency input signal is used to modulate a 675 cps signal which is developed by a vibrating interrupter and this signal is then amplified. A gain of about 120 to 130 db is obtained from three tubes (6ZAM1, VZ-6001, and UZ-6C6) and a UZ6C6 drives the interrupter.

The vibrator is of the exciting coil type, and the exciting coil is used as part of the oscillating circuit. The contact points of the vibrator are Pt to Rt alloy. The free side of the vibrating piece is made of ivory to prevent magnetic noise.

e. <u>Indicator</u>

A meter is used to indicate the presence of a signal. Incorporated with the metering system are a circuit to cut out the constant noise, a signal time duration discriminating circuit, and a voltage regulation circuit. The upper and lower limits on the signal duration are adjustable, and the usual limits of the signal are that it lasts more than 0.8 seconds and not more than 2.5 seconds. A shorter time duration is not indicated while a longer signal will show up, but it will be cut off after 2.5 seconds.

f. <u>Eddy Current Compensator</u>

The "outer compensating coil" is attached to the fuselage of the plane, and the "inner compensating coil" is wound on the outer layer of the search coil. The coils have the following electrical and physical characteristics:

(1) Outer coil

Diameter of bobbin 410mm
Number of turns 400
Electric resistance .... 12 ohms
Wire used .... 0.9mm E.C.W.

(2) Inner coil

Number of turns 3000
Electric resistance .... 15 ohms
Wire used .... 0.6mm E.C.W.

g. <u>DC Generator</u>

The DC generator is the source of voltage for the amplifier an indicator. The input power is 13.5 volts, 15 amps; the output is 350 volts, 100 milliamps.

h. AC Generator

The AC generator is the source of power for the gyroscope. The input power is 13.5 volts, 22 amps; the output power is 100 volts, 0.78 amps. at 400 cps, 3 phase.

4. Arrangement in Aircraft

A typical installation is shown in Figure 7. As much as possible, magnetic material was removed from within two meters of the search coil. Even the control cables were changed to copper instead of using conventional wire rope. The DC power circuits also were removed from the coil to prevent magnetic influence by these circuits.

5. Submarine Detecting Ability

The range of detection varies both with the types of submarine being detected and with the relative course of the plane as compared to the axis of the submarine. When passing directly above the submarine and parallel to the keel line, the detection range for a 1000 ton submarine is 120 to 150 meters (390 to 490 feet); 500-1000 ton submarine 100-130 meters (325-425 feet).

The breadth of the detectable zone is about 100 meters (325 feet) at an altitude of 50 meters (160 feet), and about 60 meters (195 feet) at an altitude of 100 meters (325 feet). (See Figure 18)

B. General Description of Sumitomo Model MAD Equipment (Special Mark 1)

1. Fundamental Principle

This model of the magnetic airborne detection equipment works on a slightly different principle from the standard Mark 1, giving better detection range. The standard Mark 1 works on the relative number of lines of force, which makes the signal dependent on the speed of the MAD plane, and the signal strength varies as $1/R^4$, where R is the distance of the plane from the target. However, the Sumitomo Model measures the quantity of absolute number of lines of force, thereby making the signal independent of the planes's speed. This increases the detection range since the signal strength varies as $1/R^3$, instead of $1/R^4$.

The method used to detect the change in the absolute number lines of force through the search coil is commonly referred to as "the bridge method", as that is the basic principle of the search coil circuit. The "Non-Linear Differential Feedback Oscillator", of which the bridge is a part, is a circuit developed by Goroku HAKATA and Masahiro ABE. A complete description of its characteristics was published in Nippon Electrical Communication Engineering, No. 15, February 1939.

The search coil is mounted as one leg of a balanced bridge. Since the inductance of the coil varies with the magnetic flux through the core, any variation in the absolute number of lines of force causes the bridge to become unbalanced.

Since the system was still sensitive to eddy current noise, the same method of compensation was used as before. In this model the inner compensating coil is mounted above the search coil on a slightly larger core than that of the search coil.

2. Component Parts

The component parts are the same in both sets with the exception of the search coil, the inner compensating coil, and the amplifier. The gyro-

scope was used in both models, although a much smaller gyro could have been used with the smaller search coil in the Sumitomo Model. The length of the search coil in the standard Mark 1 is 62cm (24.4 inches), while in the Special Mark 1 the search coil is only 10cm (3.9 inches) long.

The amplifier, while of different design, is about the same weight, and the amplifier-indicator unit has the same physical dimensions as the standard Mark 1.

3. Construction and Function of Component Parts

a. Search Coil (See Figures 18 and 19)

The search coil consists of a single coil of 600 turns wound on a 3% molybdenum alloy core. The search coil alone is 2.5cm (1 inch) long and is mounted in an aluminum holder, 5cm (2 inches) long. The search coil is mounted off-center in the holder, with two permalloy rods inserted into the holder, one from each end. The longer of the two permalloy rods serves as the core of the inner compensating coil.

b. Amplifier

The amplifier consists of a non-linear differential feedback oscillator, composed of a 3000 cps oscillator, the feedback amplifier, and the feedback bridge circuit of which the search coil is a part, and three stages of amplification. Ballast tubes are included in the bridge circuit to correct for slow variations of the circuit constants. The time constant of the ballast tubes is 40 seconds, which adapts the circuits to the local configurations of the earth's magnetic field. This prevents the bridge from becoming unbalanced by slow variations, but does not affect the detecting ability of the set, since targets produce sharp, rapid changes in the magnetic field.

c. Indicator

The indicator system is practically the same as that used in the Type 3 Mark 1, with a similar signal-time-duration discriminator circuit.

4. Arrangement in Aircraft

The arrangement with the plane is the same as in the case of Type 3 Mark 1.

5. Submarine Detecting Ability

The range of detection for the Sumitomo Model (Special Mark 1) equipment was found to be 170 meters (550 feet). A greater range could have been obtained had the system been less sensitive to the electric noise of the aircraft.

PART III - PRODUCTION

Contracts for the first MAD equipment were let to Hokushin Electric Company (gyroscope and search coil) and to Tokyo Shibaura Electric Company (filter and amplifier) in October 1943. The first production models were delivered to the Navy in April 1944. From time to time other manufacturers were contracted to disperse the manufacture of MAD equipment. Although the factories tested all equipment before delivery, due to the delicate nature of the equipment the Navy made final adjustments on all sets before installation on planes. In 1944, 3000 complete sets were ordered, but only 465 sets were delivered. The

following chart shows contracts for equipment and the actual number delivered for 1944 and 1945:

Part	Factory	1944		1945		Notes
		Ordrd	Rcvd	Ordrd	Rcvd	
Amplifier & Indicator Units	Toshiba Tsushin (KOMUKA)	3000	1000	600	50	Factories were burned down in April
	Toshiba Tsushin (YANAGIMACHI)	600	130	400	0	
	Tone Musen	250	10	750	0	
	Sumitomo Tsushin	150	0	750	0	
Search Coil & Rotating Mechanism	Tokyo Keiki	1000	400	800	0	Was damaged in April but did not stop production until June
	Hokushin Denki	2000	65	1200	100	
Vibrator	Nihon Sokuteiki			1000	2000	

A total of 137 were made available to the Army for installation on the KI 54 (HICKORY) trainer adopted for anti-submarine patrols.

The new Sumitomo Model (Special Mark 1) never got into actual production; however, 20 sets were completed by June 1945 and delivered to the Navy to be tested by the Magnetic Research Section, HAYAMA. Five of these new sets are known to have been put in operating order.

PART IV OPERATIONAL AND TACTICAL USE

The Navy first employed MAD equipment in anti-submarine warfare during the summer of 1944 between Formosa and the Philippines, and at the beginning of 1945 patrols were flown between SINGAPORE and Japan. It was used during the daytime, with radar and radar intercept being used at night. However, if a contact was made by radar, the MAD gear was immediately switched on, since the submarine would obviously submerge when approached by planes Another plan was to sweep a convoy route from CHUSAN Archipelago to SAISHU Island, to TSUSHIMA, and then to SASEBO and SHIMONOSEKI Straits. Since there was a lack of fuel at that time, they were forced to use less aggressive tactics and be satisfied with calling out MAD planes whenever ships or reconnaissance planes made contact with U.S. submarines.

The usual practice in convoy coverage was to use six planes, flying across the bow of the group. With six planes flying 100 meters apart or closer, 100% theoretical coverage is possible over a 10 knot convoy and 60% over an 18 knot convoy. In some cases when planes were not available, three planes were found to give 60% coverage over a 10 knot convoy.

The maximum number of sets installed at any one time on all types of planes was 100-150; the average being about 90-100 sets. As the year was nearing its end, the number of MAD equipped planes decreased since many of these planes were being sent on combat patrols instead. About 300 sets of the Type 3 Mark 1 were installed by the Navy on all types of planes from April 1944 until the end of the war. The following list shows the various planes equipped with MAD and the approximate number of sets installed.

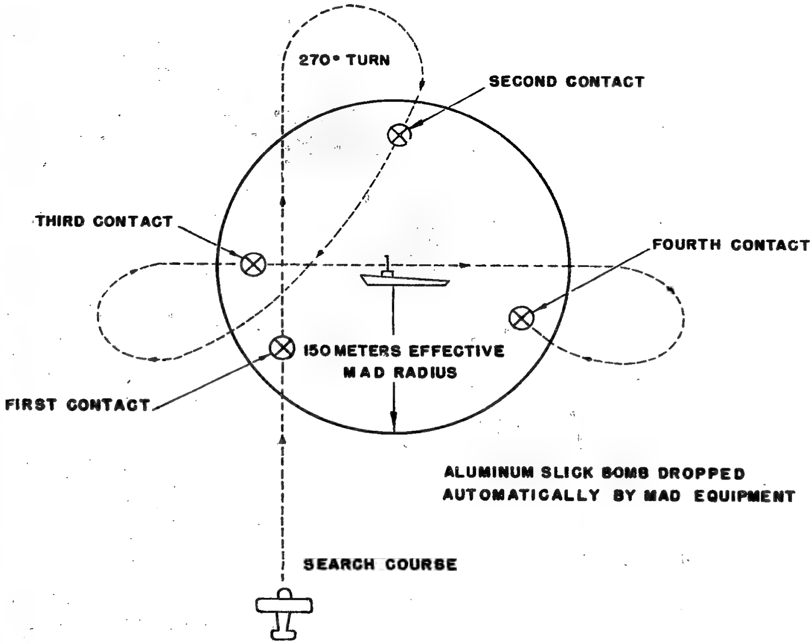

Figure 2

MAD CONTACT TRACK

Type 97 Carrier Attack Plane (KATE)		50 sets
Type 96 Land Attack Plane (NELL)		50 sets
Recce Seaplane (JAKE)		150 sets
Tokai (LORNA)		50 sets
	TOTAL	300 sets

The following air groups were assigned to work with convoys and on anti-submarine operations:

Air Group	Area	Number of Planes
903	Japan	120
951	Japan	120
901	Formosa Indo-China	200
936	Singapore Indo-China	120
	TOTAL	560

The equipment installed on these planes varied: one third were equipped with MAD equipment, one third with radar, and one third had neither. The few exceptions were the Type 96 Land Attack Planes (NELL), which carried both.

When the MAD equipment was first distributed to the operational units in the spring of 1944, it was not used to any great extent, because units were not familiar with its characteristics or uses. However, in August 1944 the 901st Air Group at TAKAO reported sub sinkings in the Formosa Straits with the aid of MAD equipment. This report encouraged other air groups to exploit the new device, and soon the four air groups were using it to an advantage. Between August 1944 and July 1945 seven submarines were sunk in the South Pacific as a result of MAD equipment and four in the waters of the home islands, according to the Japanese Navy sources. It usually took about three months to train an operator to fly a plane equipped with MAD.

Standard tactics in attacking with MAD were to fly at an altitude of 10-50 meters (33-165 feet), depending on the skill of the pilot, and to drop position markers when the sub was detected. The lower the altitude, the greater the efficacy of the equipment. Figure 2 shows a track flown by a MAD equipped plane after initial contact.

The aircraft making the contact followed the pattern of dropping markers as shown in Figure 2. In the case of convoy escort, simultaneously the convoy was turned away from the attack and was accompanied by the remaining MAD planes which continued sweeping ahead of the convoy. Usually two escort vessels were detached and proceeded to the point of contact, where they instituted an attack on the submarine. In the meantime, the plane making the original contact dropped one 250 kg (550 lbs) depth bomb using the best estimate of submarine position from the markers that were dropped. This depth bomb was usually set for 25 meters (82 feet). If planes were available to be called from bases, they usually carried four 250 kg (550 lbs) depth bombs, two set at 25 meters (82 feet) and two set at 45 meters (150 feet).

The installation of MAD equipment was extremely difficult, necessitating many changes and modifications in the plane. Late in 1944 it was decided that a special plane (TOKAI) should be built for the express purpose of carrying MAD and radar equipment for anti-submarine patrols. At the end of the war it was being produced in quantity at HAKATA on northern Kyushu.

A Very pistol was first used to mark the location of the target by firing a dye shell automatically, but this was found to be unsatisfactory because the dye was quickly absorbed by the sea. A small five pound aluminum-slick bomb

was then developed by the ordnance section to be dropped automatically on target contact. The Electrical Department in KURE discovered that in addition to its inherent weakness, the efficiency of the MAD equipment would be cut 20 to 30 percent if the submarine were demagnetized (depermed), or if appropiate magnetic countermeasures were taken.

(Figures 3 through 18 concern Type 3 Mark 1 MAD equipment.)

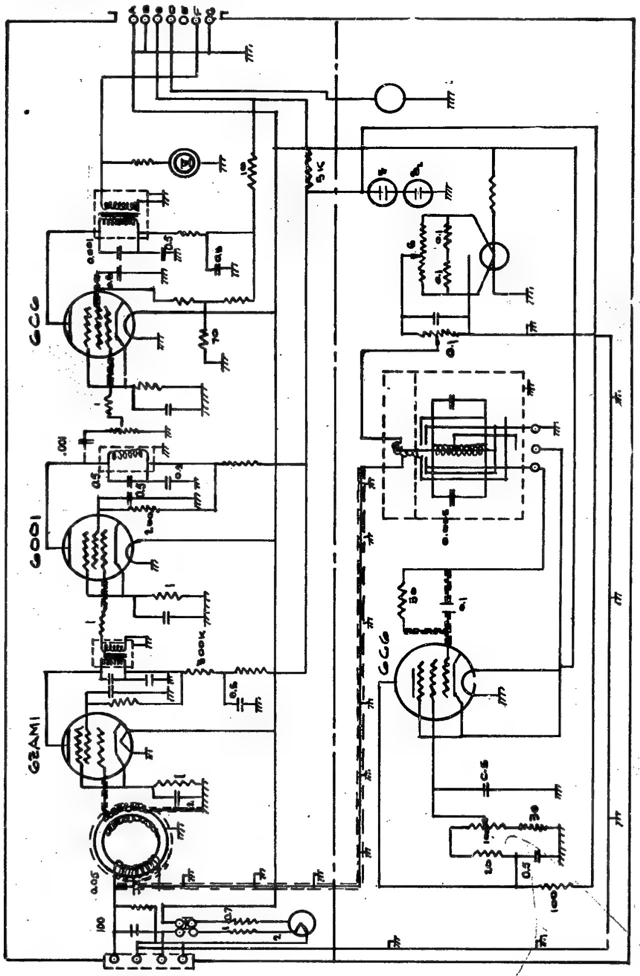

Figure 3
CONNECTION DIAGRAMS (AMPLIFIER)

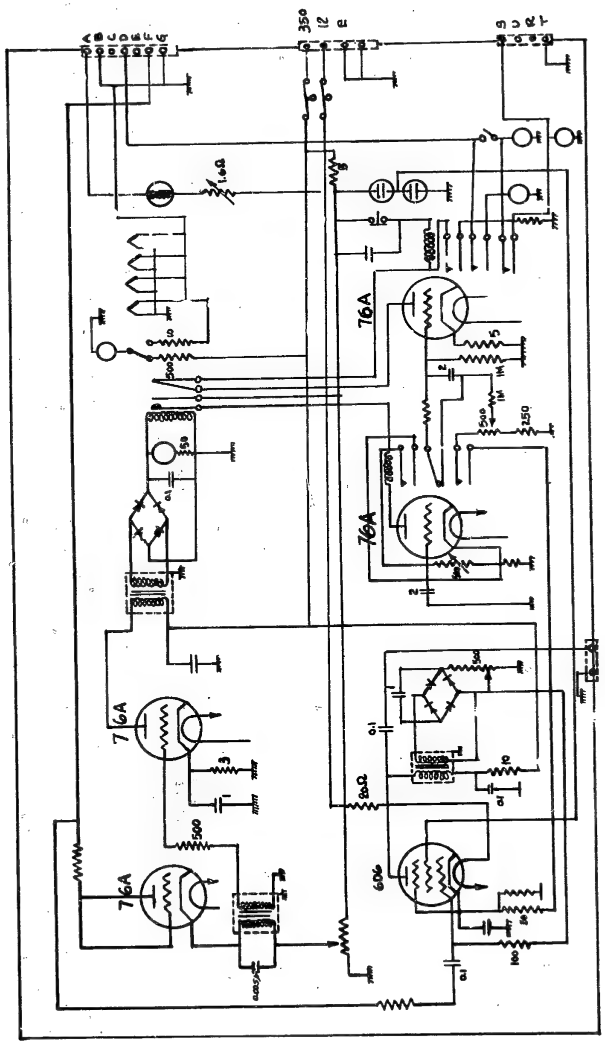

Figure 4
SIGNAL INDICATOR

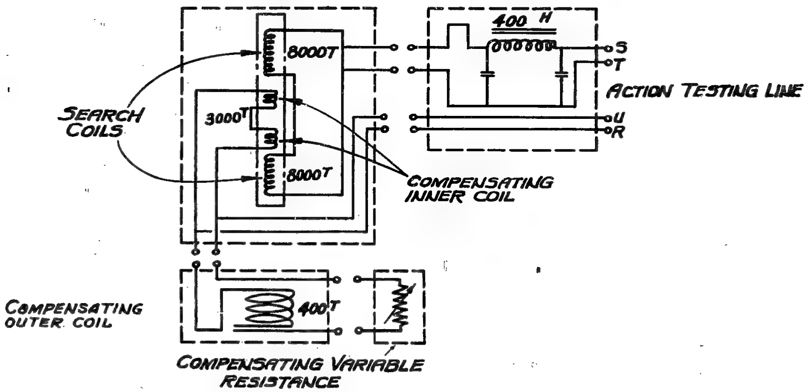

Figure 5

SEARCH COIL, FILTER AND COMPENSATOR

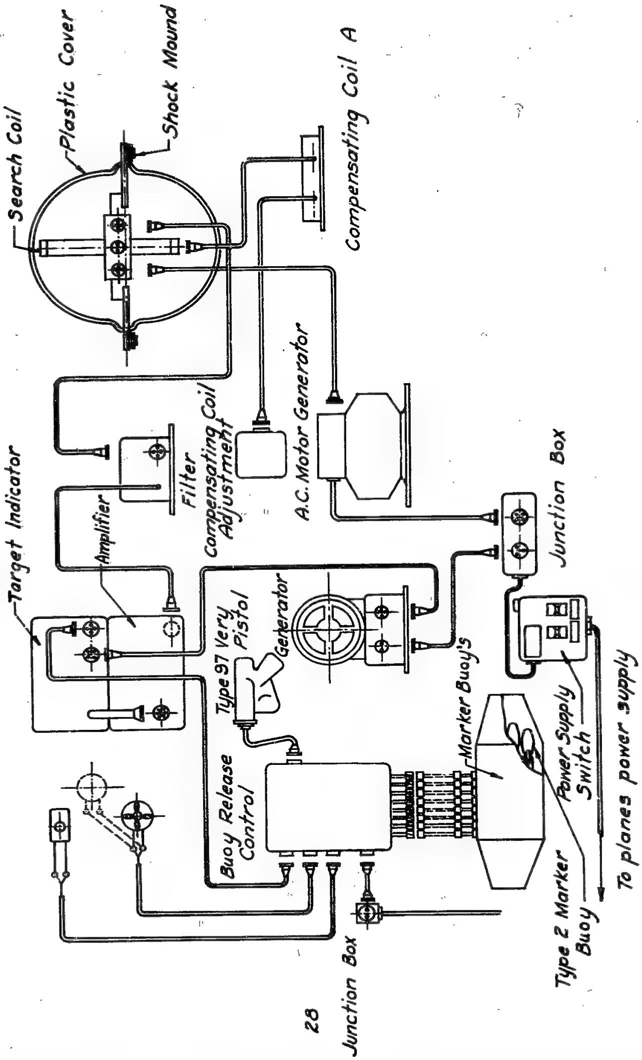

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Figure 6
INTERCONNECTION DIAGRAM

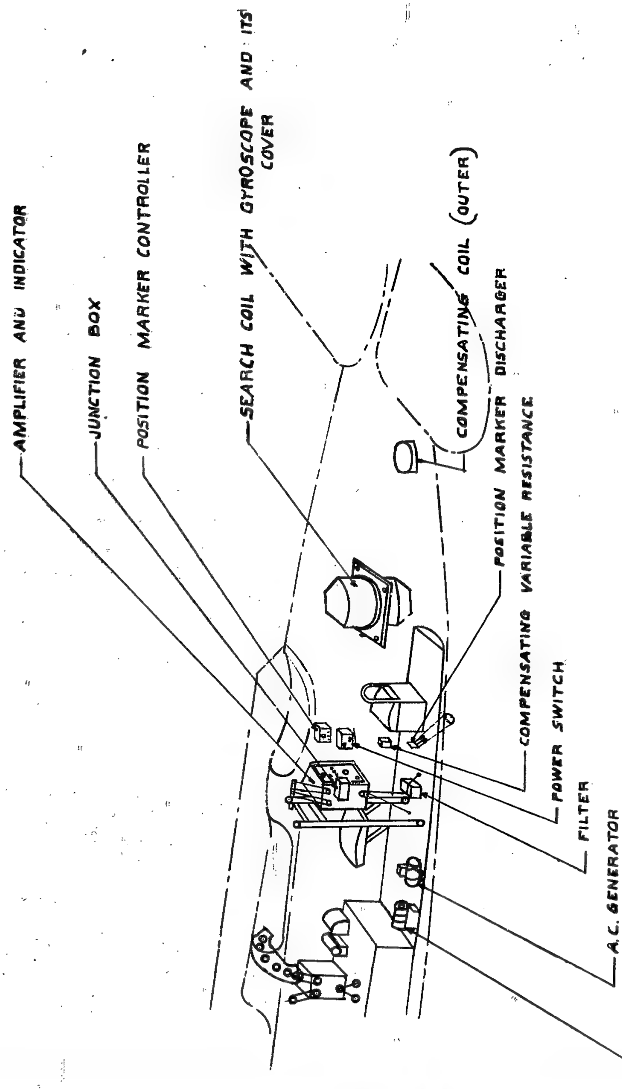


Figure 7
ARRANGEMENT OF PARTS
(Typical Installation)

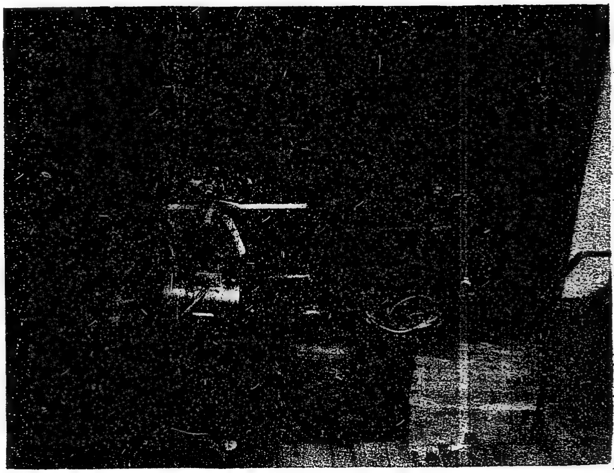


Figure 8
OVERALL VIEW OF ALL COMPONENTS

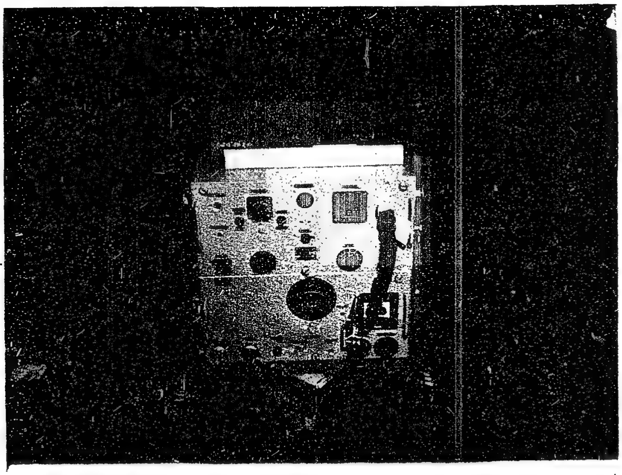


Figure 9
FRONT VIEW OF AMPLIFIER WITH OSCILLATOR REMOVED

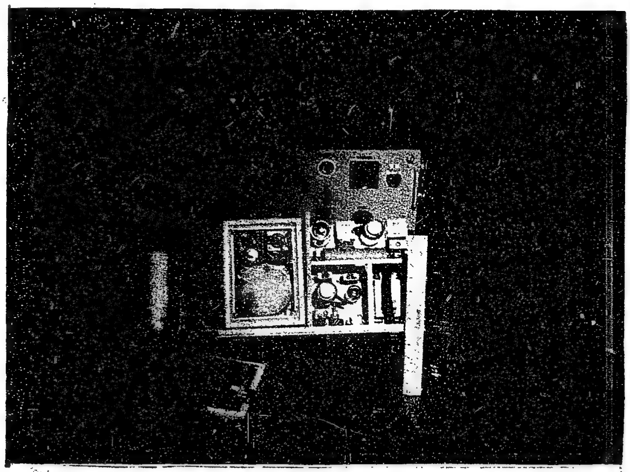


Figure 10

TOP VIEW OF AMPLIFIER UNIT REMOVED FROM AMPLIFIER-INDICATOR UNIT

Figure 11

TOP VIEW OF AMPLIFIER UNIT REMOVED FROM AMPLIFIER-INDICATOR UNIT

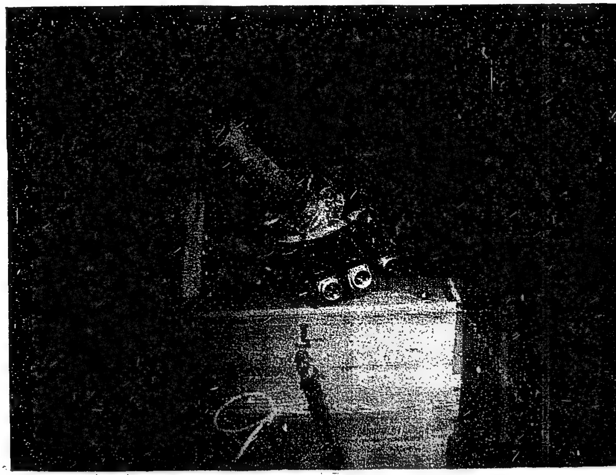


Figure 12

SEARCH COIL UNIT IN GYRO MOUNT WITH PLASTIC DOME REMOVED

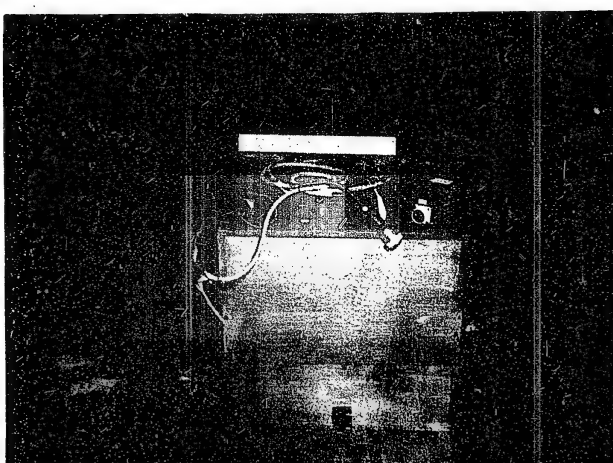


Figure 13

COMPENSATING COIL WITH CONTROL UNIT

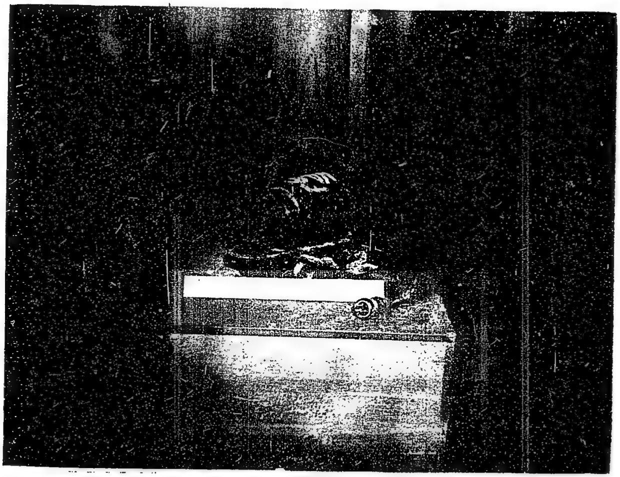


Figure 14
DC GENERATOR

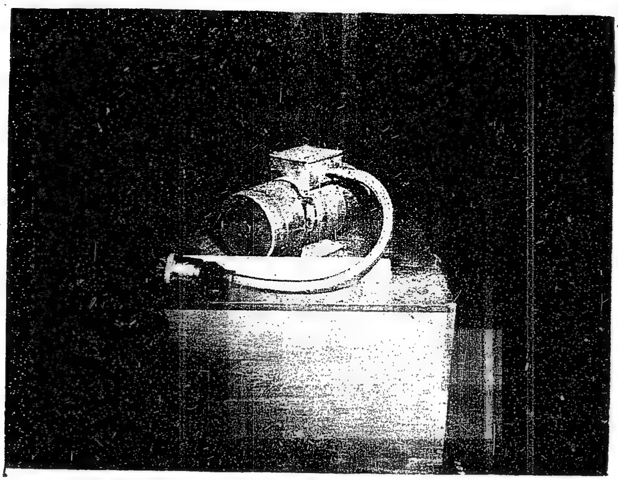


Figure 15
AC GENERATOR

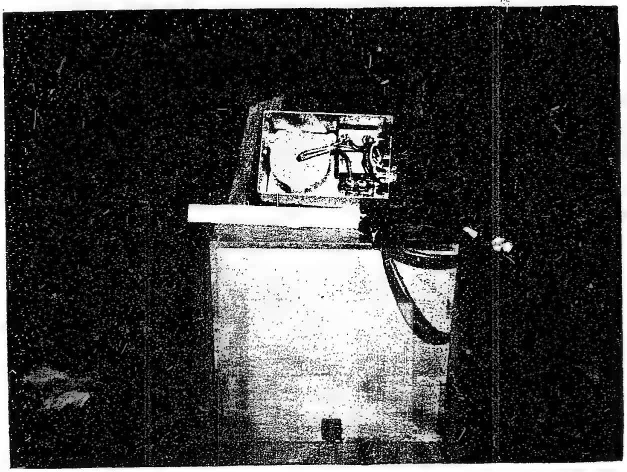


Figure 16
BOTTOM VIEW OF FILTER UNIT

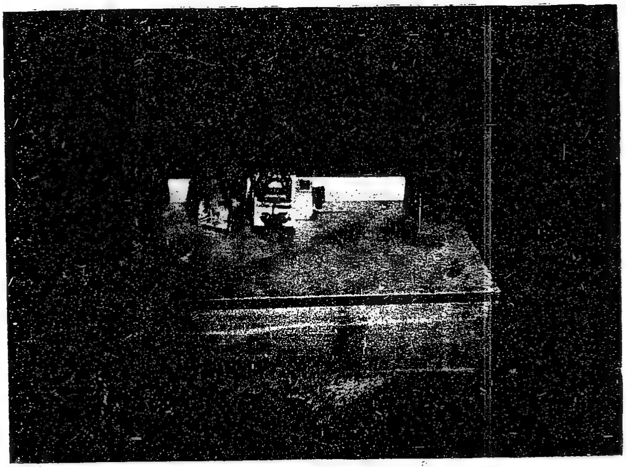


Figure 17
POWER SUPPLY SWITCH

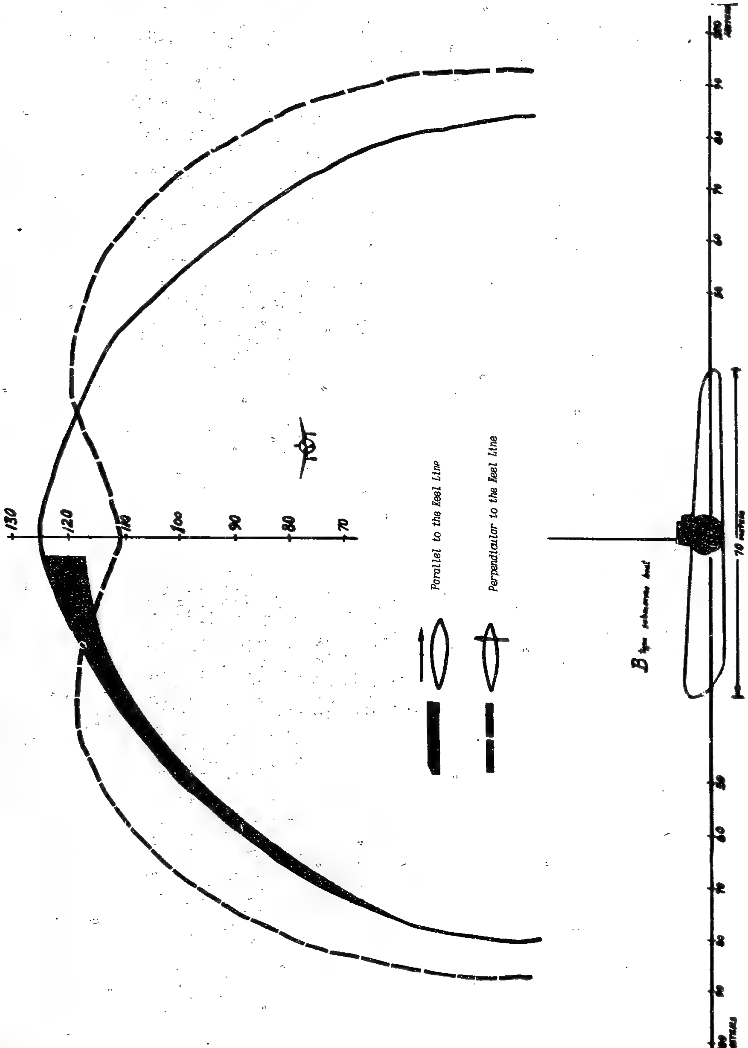
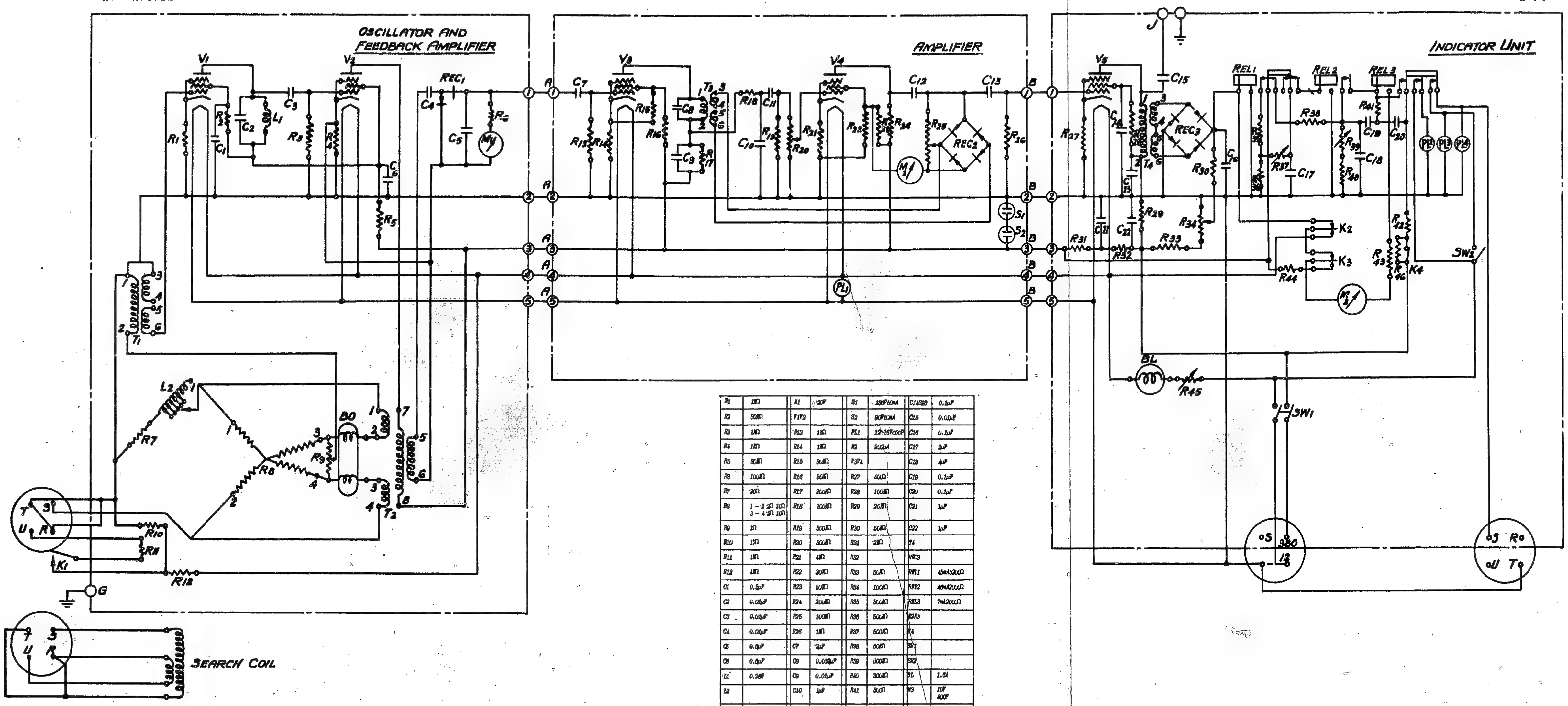


Figure 18
DETECTABLE ZONE



R1	1KΩ	M1	20V	S1	130V50mA	C14C23	0.1μF
R2	30KΩ	V1V2		S2	90V50mA	C15	0.01μF
R3	1KΩ	R13	1KΩ	PL1	12~16Vo5cP	C16	0.1μF
R4	1KΩ	R14	1KΩ	M2	200μA	C17	2μF
R5	30KΩ	R15	3KΩ	V3V4		C18	4μF
R6	100KΩ	R16	50KΩ	R27	40Ω	C19	0.1μF
R7	20Ω	R17	200KΩ	R28	100KΩ	C20	0.1μF
R8	1 - 2 2Ω 1Ω 3 - 4 2Ω 1Ω	R18	100KΩ	R29	20KΩ	C21	1μF
R9	1Ω	R19	500KΩ	R30	50KΩ	C22	1μF
R10	17Ω	R20	500KΩ	R31	2KΩ	T4	
R11	1KΩ	R21	4KΩ	R32		REC3	
R12	4KΩ	R22	30KΩ	R33	50KΩ	REL1	45mA3200Ω
C1	0.5μF	R23	50KΩ	R34	100KΩ	REL2	46mA2000Ω
C2	0.01μF	R24	200KΩ	R35	300KΩ	REL3	7mA2000Ω
C3	0.01μF	R25	100KΩ	R36	500KΩ	K2K3	
C4	0.01μF	R26	1KΩ	R37	500KΩ	K4	
C5	0.5μF	C7	2μF	R38	50KΩ	SW1	
C6	0.5μF	C8	0.002μF	R39	500KΩ	SW2	
L1	0.28H	C9	0.01μF	R40	300KΩ	BL	1.6A
L2		C10	1μF	R41	300Ω	M3	10V 400V
T1		C11	1μF	R42	30KΩ	V5	
T2		C12	4μF	R43	20KΩ	PL2	12~16V0.5cP
B.O		C13	0.01μF	R44	780KΩ	PL3	12~16V0.5cP
R1		T3	200K/4K	R45	1Ω	PL4	12~16V0.5cP
REC1		REC2		R46	300KΩ	J	

Figure 19
SUMITOMO MODEL (SPECIAL MARK 1)
MAD EQUIPMENT

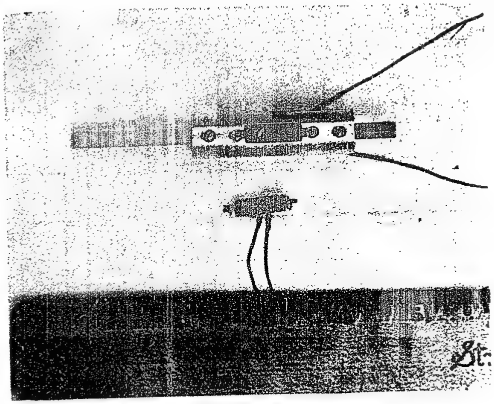


Figure 20
SEARCH COIL UNIT OF THE SUMITOMO MODEL (SPECIAL MARK 1) MAD EQUIPMENT
Showing the Coil (Below) and Its Holder (Above)

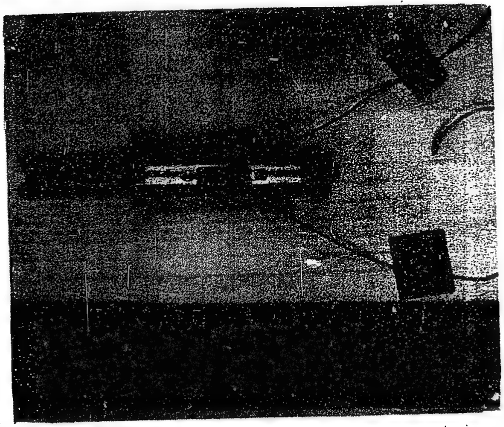


Figure 21
CLOSE OF THE SEARCH COIL.
SUMITOMO MODEL (SPECIAL MARK 1) MAD EQUIPMENT

ENCLOSURE (A)

BASIC THEORETICAL RESEARCH ON MAD
BY DR. YASUSHI WATANABE
PROF. OF ELECTRICAL ENGINEERING, TOHOKU IMPERIAL UNIVERSITY, SENDAI

Let us first consider a simple case (Figure A), where a magnetic detector is equipped with a search coil with an effective area A (meters^2) and with a number of turns N which is placed horizontally in a fuselage of a plane flying with a velocity V (m/sec) over a submarine while maintaining a constant altitude Z (meters).

Assuming that a submarine has the same magnetic properties as a magnetic dipole with a magnetic moment, M, (γm^3)*. The induced voltage due to the time variation of the vertical component, H_z (inγ) of the magnetic field caused by a submarine is given by the following equation:

$$e = N\,A\left(\frac{\partial Hz}{\partial X}Vx + \frac{\partial Hz}{\partial Y}Vy\right) \times 10^{-9}\ (volt) \text{ ----------- } (3)$$

where V_x, V_y are the velocity components.

For a better understanding of the problem, we shall take a more specific case, namely where the plane is directly over the submarine making $y = 0$ and $V_y = 0$. Then with H_z given as a function of z and x, by the following equation we arrive at (4), the induced voltage.

$$e = V\int Hz \cdot \partial y = v \cdot y \cdot 10^{-19}\ (volts)$$

$$e = NA\left(\frac{\partial H_3}{\partial X}\right) V = NA\,\frac{3\cdot 2(z^2 - 4x^2)}{(z^2 - x^2)^{7/2}} \times 10^{-9}\ (volts) \text{ -------} (4)$$

The value of e (X) is shown in Figure B, which has a maximum value at $x = 0$, i.e., directly above the submarine.

$$e_{max} = NAv\left(\frac{\partial H_3}{\partial X}\right)_{max} = NAv\cdot\frac{3M}{z^4} \times 10^{-9}\ (volts) \text{ -------------- } (5)$$

The time interval during which e appears is $T = 2z/v$.

Therefore, the range of the equipment depends on e_{max} which is proportional to $v \cdot M$ and inversely proportional to z^4. A high value of NA increases the signal voltage, but it does not necessarily increase the range since the induced noise voltage due to various magnetic disturbances is also increased.

Taking $M = 10^8$ e.m.u. for a submarine of about 1000 tons, $A = 0.1\ m^2$, $N = 2 \cdot 10^4$, $v = 100$ m/sec, then the value of e_{max} for $z = 200$ meters may be found by Eq.(5) to equal 20 microvolts and the time interval (T) is 4 sec.

At present it is not a difficult problem to amplify a high frequency low voltage of 1 microvolt. However, it is difficult to design a high gain amplifier for an extremely long signal cycle (i.e., several seconds duration). Amplification alone will not increase the range, since, as stated above, the noise is a great limiting factor.

To increase the MAD range it is necessary to increase the speed of the MAD plane, or enlarge the value of NA, for any given value of M. Vibration of the plane caused by rolling and pitching is unavoidable and this action

---

*γ = 10^{-5} gauss

ENCLOSURE (A), continued

vibrates the search coil in the earth's magnetic field inducing a noise voltage.

To calculate the quantity of this noise voltage the horizontal component of the earth's field is represented by H_{oh} (in γ), and the angle the plane makes with the horizontal is θ, which may be assumed to vary sinusoidally with an amplitude of θ_m and with a frequency of f cycles/sec. The noise voltage (e_n) is given by the following equation.

$$e_n = AN\frac{\partial}{\partial t}[H_{oh} \sin\theta] = AN\cdot Hoh \frac{\partial}{\partial t}[\sin(\theta_m \sin 2\pi ft)] \text{ ----- } (6)$$

Putting $\sin\theta \cong \theta$,

$$e_n = (AN\ Hoh\ \theta_m\ 2\pi f) \cos 2\pi ft = (e_n)_{max} \cos 2\pi ft \text{ ------ } (7)$$

Hence the signal-noise ratio becomes,

$$\xi = \frac{max\ noise}{max\ signal} \quad \frac{(e_n)\ max}{e_{max}} = \frac{Hoh\cdot\theta m\cdot 2\pi f}{\frac{3M}{z^4}\cdot v} \text{ ------------------ } (8)$$

From the result it is quite apparent that to increase the range of the MAD equipment it is necessary to suppress the interferring noise by making $\theta_m f/v$ as small as possible. For example, if we consider the case where the desired range (z) is 200 meters for $M = 10^8$ e.m.u., and $v = 100$ m/sec, $Hoh = 3 \times 10^4\gamma$, and we wish to diminish the signal-to-noise ratio to 1, the limit of $\theta_m \cdot f$ becomes 0.00005. Therefore, if f is taken to be equal to 0.2, then θ_m has to be less than 0.0003 radian, or nearly one minute.

To stablize the search coil within such small limits presents a difficult problem even if the coil is mounted in a gyroscope. The only alternative is to use a vertical magnetic core of high permeability on which the search coil is wound. This effectively only amplifies the vertical component of the magnetic (signal) field.

The factor that must be considered is that the plane moving in the earth's field produces eddy currents which produce an undesirable effect of noise. This may be eliminated to a large degree by the use of compensating coils with a current passing through them which would produce a current equal and opposite to the eddy current generated by the plane.

ENCLOSURE (A), continued

Fig. A

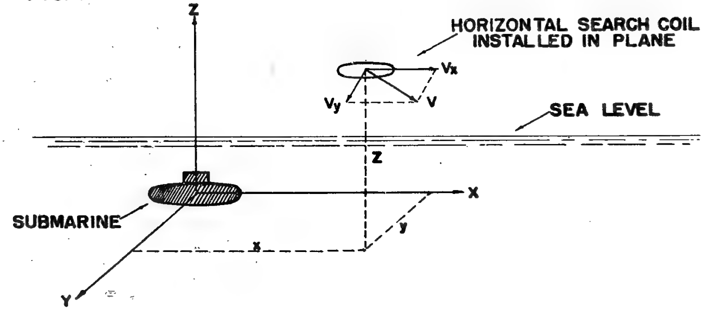
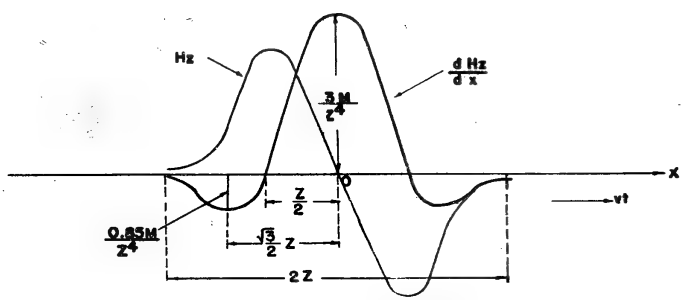


Fig. B



JUST ABOVE A SUBMARINE

ENCLOSURE (B)

TYPE 3 MARK 1 MAD EQUIPMENT TEST RESULTS

(Test Results of Main Components of Equipment Forwarded to NRL and Freeman Field, Seymour, Ind.)

The following data were obtained by Japanese Navy engineers assigned to the adjustment and testing of MAD equipment for shipment to the United States.

1. <u>Search Coil and Gyroscope</u>

	Resistance		Insulation (megohm)		
Coil Number	Search Coil (kilo-ohm)	Compen. Coil (ohm)	Search Coil to Ground	Compen. Coil to Ground	Compen. Coil to Search Coil
HO I 320	17	12	100	100	
HO I 400	18	12	80	100	
HO I 335	17	12	70	100	150
HO I 362	18	12	80	100	
HO I 391	18	14	100	150	150
HO II250	17	13	90	80	100

Sensitivity: normal. Condition: good.

* * * * *

OPERATIONAL NOISE TEST

Coil Number	RPM	Swing (xy)		Swing (z)	Rolling		Repeated Shock		Noise	Condition
		E-W	N-S		E-W	N-S	(XZ)	(Z)		
HO I 320	16000	30	35	20	30	20	10	15	2	good
HO I 400	16000	30	30	10	15	20	10	15	5	very good
HO I 335	16000	30	30	25	20	30	10	15	2	good
HO I 362	16200	25	30	20	10	15	10	5	2	very good
HO I 391	15000	30	30	15	20	25	25	15	7	good
HO II250	16100	35	20	10	20	20	15	20	3	good

1 m swing 30cm swing $\theta = 30^{\circ}$
T = 2 sec T = 1 sec T = 1 sec T = 0.5 sec

Figures in above table are readings of the amplifier output meter in volts. Amplifier gain is $2V/\mu V$.

ENCLOSURE (B), continued

2. Amplifier and Indicator Unit

Amplifier Model	Max. Gain	Amplified Noise at Motor Gen.	Action of Indicator	Condition
SHI I 758	5V/μV	8 V	normal	good
SHI I 687 (667)	3V/μV	0	normal	good
SHI I 716 (752)	4V/μV	10 V	normal	good
SHI I 793	5V/μV	0	normal	very good
SHI I 717	5V/μV	5 V	normal	good
SHI I 810	4V/μV	5 V	normal	good

ENCLOSURE (C)

LIST OF MAD EQUIPMENT SHIPPED TO NRL

NavTechJap No.	Box Number	Contents
JE21-6335.1	I	Search Coil (1/4)
JE21-6336.1	II	Search Coil (2/4)
JE21-6337.1	III	Search Coil (3/4)
JE21-6338.1	IV	Search Coil (4/4)
JE21-6335.2	V	Search Coil Cover (1/4)
JE21-6336.2	VI	Search Coil Cover (2/4)
JE21-6337.2	VII	Search Coil Cover (3/4)
JE21-6338.2	VIII	Search Coil Cover (4/4)
JE21-6335.3	IX	Amplifier (1/4)
JE21-6336.3	X	Amplifier (2/4)
JE21-6337.3	XI	Amplifier (3/4)
JE21-6338.3	XII	Amplifier (4/4)
JE21-6335.4 JE21-6336.4 JE21-6337.4 JE21-6338.4	XIII	(4) Motor Gen. (AC)
JE21-6335.5 JE21-6336.5 JE21-6337.5 JE21-6338.5	XIV	(4) Motor Gen. (AC)
JE21-6335.6 JE21-6336.6 JE21-6337.6 JE21-6338.6	XV	(4) Filter
JE21-6335.7 JE21-6336.7 JE21-6337.7 JE21-6338.7		(6) Compensating Resistance (and two spares)
JE21-6335.8 JE21-6336.8 JE21-6337.8 JE21-6338.8		(6) Power Switch
JE21-6335.9 JE21-6336.9 JE21-6337.9 JE21-6338.9	XVI	(4) Outer Compensating Coils

ENCLOSURE (C), continued

NavTechJap No.	Box Number	Contents
JE21-6335.10 JE21-6336.10 JE21-6337.10 JE21-6338.10	XVII	Cables
JE21-6335.11 JE21-6336.11 JE21-6337.11 JE21-6338.11	XVII	Plugs
JE21-6335.12 JE21-6336.12 JE21-6337.12 JE21-6338.12	XVII	Vibrators (15)
JE21-6335.13 JE21-6336.13 JE21-6337.13	XVII	Gain Tester (3)
JE21-6335.14 JE21-6336.14 JE21-6337.14 JE21-6338.14	XVII	Tools
JE21-6335.15 JE21-6336.15 JE21-6337.15 JE21-6338.15	XVIII	Tubes (8) 6ZAMI (18) 76 (8) 6D6 (15) 6001 (10) pilot lamp (20 cp) (50) pilot lamp (½ cp) (10) VRD 135/50 (10) VRD 90/50 (10) Ballast Tube (25) Thermo Couple
JE21-6339.0	XIX	New Experimental Amplifier for JE21-6339.0 "Special" Mark 1 MAD Equipment

(Note: Eight boxes of MAD equipment also were shipped to Freeman Field, Seymour, Indiana.)

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ENCLOSURE (D)

LIST OF DOCUMENTS FORWARDED TO THE WASHINGTON DOCUMENT CENTER

NavTechJap No.	ATIS No.	Description
ND50-4001a	3149	Type 3 Mark 1 MAD equipment handling instructions
ND50-4000a	3150	Type 3 Mark 1 MAD equipment annex to handling instructions